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Object:

Last month at the Laboratoire National des Essais (L.N.E. or French National Test Laboratory), we conducted measurements on the thermal characteristics of ONDULINE DURO-S PPHR sheets (Petit-Rechain), since the last test report dates from 1953.

RESULTS AND OBSERVATIONS (see attached 1997 test report)

	Sheet type	λ (kcal / h.m.°C)	λ (W / m.°C)	R (m^3 . K / W)
1953 (recall)	ONDULINE + paint ISOLA silver	0.084 (test report 1953)	0.096	0.088
1997	DUROS-S PPHR RED (P 8104 B) from Petit-Rechain	0.085	0.099 (test report 1997)	0.08

By expressing the λ values in the same units, we can see that there is consistency between the 1953 results and the 1997 values.

For information, we have attached an extract from the D.T.U. document (THK rules), which gives "effective λ" values for materials such as fibre cement or cellulose fibre cement and compressed cork.

Please note that these extracts indicate "effective λ" values, which are always greater than the λ values determined according to French standard NFX 10-021 (test conditions used for ONDULINE sheets). "Effective λ" values take into account the effect of moisture in the material, which in the case of ONDULINE can affect the λ value (increasing it as a function of the moisture content in the roofing sheet).

L. LAINE

TEST REPORT

Requesting Party:	OFITECH Zone Industrielle B.P. 17 76480 YAINVILLE FRANCE
Date of Request:	Letter E.T. 970808/LL.LNE04 dated 11/08/97.
Purpose:	Determination of the thermal resistance and thermal conductivity of bituminous roofing sheets.
Reference Document:	French standard NF X 10-021 (December 1972).
Sample Identification:	ONDULINE DURO-S PPHR (7070916-1 / 7070916-2)

1. SPECIMEN IDENTIFICATION

The Requesting Party has provided the L.N.E. with a series of 20 specimens of bituminous roofing sheets identified by the trade name ONDULINE DURO-S PPHR RED.
These roofing sheets, which were specially produced in flat form for the purposes of these tests, have nominal dimensions of 610 mm x 610 mm x 2.9 mm.
They are covered with a red coating on the outside (exposed) face of the sheet.

2. TEST SPECIMEN CHARACTERISTICS

2.1 TEST SPECIMEN PREPARATION

To satisfy the measurement requirements, the two test specimens are each composed of a stack of ten samples.

2.2 TEST SPECIMEN CHARACTERISTICS

The physical characteristics of the test specimens are presented in Table 1.

Specimen Ref.	No. of samples	Dimensions L x w x d (mm)	Total Surface density (kg/m^2)	Unit Surface density (kg/m^2)
7070916-1	10	611 x 611 x 29.45	26.9	2.69
7070916-2	10	611 x 611 x 29.37	26.7	2.67

L = length w = width d = thickness

Table 1: Test specimen characteristics

3. MEASUREMENT CONDITIONS

The thermal resistance measurement was conducted in compliance with the provisions of French standard NF X 10-021 (guarded hot plate method). The main characteristics of the test apparatus and the operating procedure are described in Appendix 1.
During the measurements, the test specimens were placed in the test apparatus with the red coating on the cold side.

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4. MEASUREMENT RESULTS

The thermal resistance measurements on the test specimens (stack of 10 samples) are gathered in Table 2.

Sample Identification :												7070916-1 / 7070916-2
Mean thickness for measurement d_m :												29.41 mm
Heat Flux Density (W/m^2)	Mean Specimen Temperatures (°C)							Temperature Difference (°C)			Thermal Resistance ($m^2.K/W$)	Thermal Conductivity (W/m.K)
	Hot Sides		Cold Sides		Means							
$\varphi/2A$	θ_{c1}	θ_{c2}	θ_{f1}	θ_{f2}	θ_{m1}	θ_{m2}	θ_m	$\Delta\theta_1$	$\Delta\theta_2$	$\Delta\theta_m$	R_m	λ_m
33.35	14.91	15.04	5.10	4.99	10.00	10.01	10.01	9.81	10.05	9.93	0.298	0.09878
The thermal conductivity values presented in this table are not effective thermal conductivity as defined in DTU "THK Rules", nor are they certified product values.												

$\theta_{m1} = (\theta_{c1} + \theta_{f1})/2$ $\theta_{m2} = (\theta_{c2} + \theta_{f2})/2$ $\theta_m = (\theta_{m1} + \theta_{m2})/2$

$\Delta\theta_1 = (\theta_{c1} - \theta_{f1})$ $\Delta\theta_2 = (\theta_{c2} - \theta_{f2})$ $\Delta\theta_m = (\Delta\theta_1 + \Delta\theta_2)/2$

Table 2: Measurements conducted on the pair of specimens 7070916-1 / 7070916-2

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5. SUMMARY OF MEASUREMENT RESULTS

In light of the stacking of several samples during the measurements, the thermal resistance of an ONDULINE DURO-S PPHR sheet is calculated by dividing the measured thermal resistance (see Table 2) by the number of samples in each test specimen.

The summary of results is presented in Table 3.

Product ID	Mean Temperature θ_m (°C)	Mean Thickness d_m (mm)	Thermal Resistance R_m (m^2.K/W)	Thermal Conductivity λ_m (W/(m.K))
ONDULINE DURO-S PPHR	10.01	2.94	0.030	0.099

Table 3: Summary of results

Trappes, 15 September 1997

MATERIALS Department Head — Technical Manager

Loic CHESNE — Sylvie QUIN

The results cited herein apply only to the samples, products or materials submitted to the LNE laboratory, as defined in the present document.

APPENDIX 1: MEASUREMENT METHODOLGY AND EXPRESSION OF RESULTS

Measurements are conducted using a conductivity meter operated under the conditions defined in French standard NF X 10-021.

The conductivity meter is an apparatus with two specimens stacked horizontally, with an auxiliary guard and insulation around the outside.
It is used to measure the thermal conductivity of poorly conductive materials in the following operating ranges:

- thermal conductivity: 0.015 to 1.5 W/(m.K)
- specimen thickness: 0.010 to 0.160 m
- mean temperature: 288 K to 333 K (-10°C to +60°C)

1. MEASUREMENT PRINCIPLE

The operating principle for a *guarded hot-plate apparatus* consists in simulating heat transfer conditions, in a unit with finite dimensions, through an infinite slab bounded by two parallel, isothermal planes (maintenance of a uniform, one-way thermal field).
After a constant, uniform heat flux density has been reached through the two specimens placed on either side of the guarded hot plate, the surface flux is determined by measuring the electric power that dissipates in the measurement zone of the hot plate (heat flux Φ) and by measuring the surface of the measurement zone A. Then, the mean temperatures of the hot sides, θ_{c1} and θ_{c2}, and cold sides, θ_{f1} and θ_{f2}, of the specimens are determined.

2. DESCRIPTION OF APPARATUS

The measurement apparatus includes the guarded hot plate (heating plate and cooling plates) and instrumentation for control and measurement of plate and specimen temperatures as well as the power dissipated in the measurement zone.
The specimen stack (composed of the cold plates, the guarded hot plate and the two specimens) is placed in an insulated chamber (external dimensions: 1.10 m x 1.10 m) set to the mean temperature for the test specimens. The chamber with specimens is then placed in a climate-controlled room.
To minimise heat escaping from the sides of the plates and specimens, the space between the outer ring (side guard) and the guarded hot plate is filled with light insulating aggregate (non-hygroscopic vermiculite).

The main dimensions of the apparatus are as follows:

- total surface of hot and cold plates: 610 mm x 610 mm,
- width of the measurement zone (from centre of slit to centre of slit): 300 mm,
- slit width: 1 mm,
- guard width (from centre of slit to outer edge of guard): 155 mm.

2.1. MEASUREMENT STACK

The test device is composed of a horizontal stack with the following elements (see Figure 1, Appendix 1):

- In the centre, a heating plate known as the guarded hot plate,

- Two identical specimens cut from the test material and placed symmetrically on either side of the hot plate,

- The other side of each specimen is in contact with a liquid circulation plate known as the cold plate,

- The temperature measurements are conducted by means of five thermocouples per side, placed in the central square of each plate. The temperature measurements for the plates correspond to the surface temperatures for the test specimens. In the case of very stiff materials, the thermocouples are placed on each side of the specimens in order to measure their surface temperatures.

2.2. CHARACTERISTICS OF STACK ELEMENTS

2.2.1 Heating Plate

The heating plate is composed of two electrically powered heating elements which are placed between two metal plates for temperature uniformity. These plates have a central zone, 299 mm x 299 mm, that is separated from the outer zone by a slit, 1 mm in width, thus forming a heat cut-off.

The central heating element (460 mm x 460 mm) and the outer element are supplied with DC power by two independent circuits.
The power supplied to the outer element is automatically adjusted by a zero regulator, whose input signal is supplied by a thermopile (sensitivity: 2240 µV/°C) which amplifies the temperature disequilibrium of the uniformization plates on each side of the slit.

2..2.2 Cooling Plates

These are made from an aluminium plate in which a double-helix coil has been machined. Glycol water (-15°C to +55°C) is circulated through the coils from a thermostatically controlled bath (internal regulation of bath: ±0.02°C).

2.3 MEASUREMENT ACQUISITION AND PROCESSING

The acquisition of all required measurements (thermoelectric forces for the various temperatures, supply voltage and current in the measurement zone, and thermal disequilibrium between the central square and the guard ring), the immediate processing of these measurements and the storage of these data are performed at a pre-defined polling interval by a program implanted in a micro-computer that is connected to the measurement unit.

3. EXPRESSION OF RESULTS

The results for thermal resistance, R_m (m^2.K/W), and/or mean thermal conductivity for the pair of specimens, λ_m (W/(m.K)), are determined after validation of the two convergence criteria (slope and standard deviation), which show that a stationary regime has been obtained in a 16-hour window, during which a measurement is made every two minutes (n=480 minutes). The two values, R_m and λ_m, are given in the following formula:

$$R_m = \frac{dm}{\lambda_m} = \frac{1}{n} \sum \frac{2 S \Delta \theta_m}{\Phi}$$

where:
- Φ : power dissipated in the measurement zone (W)
- d_m : mean thickness of the two specimens (m)
- S : measurement surface area (m^2) (square 300 mm x 300 mm)
- n : number of measurements
- $\Delta\theta_m$: difference in mean temperature (K)

$$\Delta\theta_m = \frac{(\theta_{c1} - \theta_{f1}) + (\theta_{c2} - \theta_{f2})}{4}$$

θ is the mean temperature on one side
The subscript c indicates the hot side.
The subscript f indicates the cold side.
The subscript 1 indicates the top side.
The subscript 2 indicates the bottom side.

The thermal resistance, R_m, and/or the thermal conductivity, λ_m, are then defined by the mean temperature, θ_m, for the specimen:

$$\theta_m = \frac{\theta_{c1} - \theta_{f1} + \theta_{c2} - \theta_{f2}}{4}$$

End of test report.

Cold upper plate

Specimen 1

Guarded hot plate

Specimen 2

Cold bottom plate

Figure 1: Measurement stack

Material	Dry Density (ρ) in kg/m³	Effective Thermal Conductivity (λ) in W/(m.K)
3.46 Particle board panels (agglomerated wood fibre panels containing a cement binder) Defined in accordance with French standard NF B 56-010. See paragraph 4.33.	450 to 550 350 to 450 250 to 350	**0.15** **0.12** **0.10**
3.47 Cork, defined in accordance with French standard NF 7-000 - Compressed.. - Pure expanded: please refer to section 3.53 - Expanded, agglomerated with pitch or synthetic resins: please refer to section 3.53	500	**0.10**
3.48 Straw, compressed..	300 to 400	**0.12**
3.5 MANUFACTURED INSULATING MATERIALS These materials have thermal conductivity of at most 0.065 W/(m.K) (see French standard NF P 75-101), are factory-made and are sold as slabs, panels or rolls. These slabs, panels or rolls may be described in a Qualification Certificate, particularly as concerns their thermal resistance. In such a case, please refer to section 4.6. In the absence of a certificate, the effective thermal conductivity to be used in calculations is indicated in the sections below for each family of materials. A family is defined by a standard, a manufacturing process and, if needed, by physical characteristics that are specific to that family. Manufacturers that refer to a family in their documentation must be able to prove that their products meet the indicated identification criteria. In the absence of such proof, the values given in the “other products” line shall apply.		
3.51 Balsa wood	$60 \leq \rho \leq 120$	**0,054**
3.52 **Mineral wool** as defined in accordance with French standards NF B 20-001 and NF B 20-109. The volume-based measurements indicated in this section are nominal apparent densities as defined in French standard NF B 20-105 (surface density divided by the nominal thickness indicated by the manufacturer). These values are exclusive of any coatings present. Please refer to section 4.6 to determine the thermal resistance of these products.		

Material	Dry Density (ρ) in kg/m³	Effective Thermal Conductivity (λ) in W/(m.K)
3.632 **BITUMEN**		
Flexible roofing felts and sheets impregnated with bitumen.	1000 to 1100	**0.23**
3.7 METALS		
Pure iron	7870	**72**
Steel	7780	**52**
Cast iron	7500	**56**
Aluminium	2700	**230**
Duralumin	2800	**160**
Copper	8930	**380**
Brass	8400	**110**
Lead	11340	**35**
Zinc	7130	**112**
3.8 OTHER MATERIALS		
3.81 Clay and Terra Cotta Products		
3.811 LATERITE MUD, STABILISED-EARTH CONCRETE, COMPRESSED EARTH BLOCKS		
3.812 TERRA COTTA	$1770 \le \rho \le 2000$	**1.1**
Density varies between 1700 and 2100 kg/m³, and the thermal conductivity ranges from 1.0 to 1.35 W/(m.K). The mean values are	1800 to 2000	**1.15**
For lighter terra cotta with density less than 1700 kg/m³, please refer to certification documents or Technical Assessments.		
3.82 Coating and Sealing Mortars	1800 to 2100	**1.15**
3.83 Fibre Cement and Cellulose Fibre Cement		
3.831 FIBRE CEMENT	1800 to 2200 1400 to 1800	**0.95** **0.85**
3.832 CELLULOSE FIBREE CEMENT	1400 to 1800 1000 to 1400	**0.46** **0.35**
3.84 Vermiculite-based sheets agglomerated with silicates	400 to 500 300 to 400 200 to 300	**0.19** **0.14** **0.10**
3.85 Glass	2 700	**1.1**
3.85 Bulk materials The characteristics of these materials depend on how they are applied; these characteristics are given in Chapter IV.		